Introduction to Piping Engineering

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INTRODUCTION TO PIPING ENGINEERING
A SunCam online continuing education course

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1.0   DEFINITION OF PIPING ENGINEERING

1.1 Piping Engineering Goal

Piping Engineering is a discipline that is rarely taught in a university setting, but is extremely important for the safety of plant personnel, safety of the public, and reliability of a facility.

The Goal of Piping Engineering is:

ASSURE A PIPING SYSTEM IS

➢   **SPECIFIED AND DESIGNED**
➢   **FABRICATED AND ERECTED**
➢   **INSPECTED AND TESTED**
➢   **OPERATED AND MAINTAINED**

TO PERFORM RELIABLY AND SAFELY IN ALL EXPECTED CONDITIONS, FOR ITS DESIGN LIFE.

When plant evaluations and repairs of existing pipe, are being performed, often plant operations and maintenance personnel ask, "Is it going to be safe to work around here?" An answer they always appreciate from the piping engineer; "I'll be out here checking on the pipe when the plant starts up." The plant personnel just want to be assured that we are doing everything in our power to make the piping system safe to operate. This experience leads to a more personal definition of Piping Engineering:

"WHAT IS REQUIRED FOR ME TO BE SAFE STANDING NEXT TO THIS PIPE WHILE IT IS OPERATING?"

To the uninitiated, this personal definition may seem a little alarmist, but it is based on reality. Pipes do fail, and sometimes with catastrophic results. Operations and maintenance personnel at plants understand the potential risks. While some major failures of high pressure lines have killed personnel, sometimes even relatively low pressure releases can cause injury and extended plant shutdowns. A release of toxic, flammable fluids or hazardous chemicals is a tremendous risk to personnel and neighbors and a large financial risk to operators.

Engineers sometimes get caught up in the numbers and minute detail of the designs. While details are important, it is also important to personalize the work and think about the full picture of the installation, and the long - term equipment's use. While you may

not be standing next to that pipe or equipment, someone will be – and their safety should always be in your mind when considering if all appropriate considerations have been made, and the calculations are accurate and conservative.

1.2   Why Is Piping Engineering So Difficult?

On the surface, pipe is pretty simple – a round bar with a hole in it to transport a fluid or gas. However, there is no other equipment within a typical plant that is subjected to so many different loading conditions over its life.

➢ Pipe is supported at point locations, and must be able to support itself without undue sagging or bowing.
➢ The weight of the pipe may change from empty to full at times, which on large diameter pipes can create dead weight double or triple the empty weight.
➢ Temperatures vary from ambient to operating, sometimes greater than 1200F in process or steam systems, or less than -300F in a cryogenic application.
➢ As the pipe heats and cools it moves due to thermal expansion. Pipe flexibility and pipe supports must accommodate this movement.
➢ Pipe is attached to equipment, which has a limited capacity to support the pipe.
➢ As the pipe ages, it tries to find its lowest stress level, and thus it "relaxes" – almost always into a different position than the theoretical analysis calculates.
➢ Flexible pipe is sometimes analogous to supporting spaghetti, as it bends and twists from all of its various loading conditions. Changing a support in one location sometimes has a major effect on pipe movement 80 feet away.
➢ Depending on the operating conditions, the pipe material may degrade over time due to creep, embrittlement or some other metallurgical phenomena.
➢ Pipe stress analysis is not very exact. There is a great deal of judgment that is required in evaluating the results.
➢ Standard pipe specifications allow +, - 12.5% variation in wall thickness. While most pipe thickness is within 1% to 2% of nominal; at any welded joints, the actual wall thickness may be 12.5% different than expected.
➢ There are a high number of different components in each piping system: elbows, straight pipe, reducers, valves, flow meters, thermowells, pressure taps, branch connections, flanges, gaskets, bolts, etc. In a typical plant, when the sizes and schedules of all these components are counted, there may be much more than 10,000 different components. This represents a large quantity of data to understand, and to properly identify and track through the design, installation and operation of plants.
➢ Even with great engineering and design, the installation is subject to irregularities in the fabrication and erection of the pipe. Pipe fitters will rotate weld joints and pull pipe to "make the pipe fit". While some of this can be controlled with very strict Quality Assurance, the reality is that it will occur. Engineering must try to

control and then assure enough conservatism in the design that fabrication tolerances do not create significant problems.

➢ Pipe has its limitations in age and usage. Pipe may corrode, erode, metallurgical characteristics may age; all of which will change its strength and flexibility characteristics.

➢ Pipe supports springs can wear out, or fail due to overload, corrosion or other external factors.

➢ Modifications have often been made to existing piping systems without sufficient consideration, and the result has been damaged pipe and an unreliable plant.

1.3 Class Purpose

This class is designed to introduce the student to the basic concepts of piping engineering. By the end of the course you should know

o The location of information on the design, engineering, fabrication and inspection of pipe.
o Understand how to identify a piping system
o Understand the basic loading conditions
o Understand the basic failure modes
o Identify the different types of pipe supports and their purposes
o Understand the information required to perform a pipe stress analysis.

There are several basic principles that will be described and stressed throughout this course.

1. Piping systems can and do fail. Engineering should always consider possible failure modes and work to avoid the possibility that the piping system will fail.
2. Even in the best-engineered systems, there are assumptions built into the design. The engineer and designer should recognize these assumptions and allow appropriate allowances.
3. Pipe stress analysis is only one portion of piping engineering. There are other major considerations before performing the stress analysis. If the preparation work has been done well, very few piping system designs will fail the pipe stress evaluation criteria.
4. Because of the high number of possible loading conditions, and the numerous variations in components that make up a typical piping system, it is doubtful if the pipe stress is accurate by better than plus - minus 20%. Do not design to the limit of the pipe allowable stress unless there is a good understanding of the loading conditions and a strong quality assurance program.
5. Pipe must always be viewed as a system from equipment to equipment, including branch lines, and pipe supports.
6. As with all engineering design, understand the purpose and operation of the system before performing the detailed design.

7. Pipe is an industrial plant must be maintained. It is commonly thought that properly engineered and installed pipe is "good forever" and can be left as is. The vast majority of pipe will operate successfully for decades, but some systems are known to be susceptible to damage and failure. Periodic inspections and repairs should be planned and performed on the appropriate piping systems to assure safe and reliable operation.

2.0 DESIGN BASIS

Typically a Piping & Instrumentation Diagram (P&ID) drawing sets the fundamental requirements showing the pipe size, schematic of the equipment connections and primary branch connections. This is considered the starting point for Piping Engineering.

Before routing and engineering the pipe, a design basis must be set. In this section the basic requirements are defined. Later sections describe some of the requirement details.

2.1   Design Codes

The design basis for any project should state the required design codes for materials and equipment. This is usually set by the client, and the engineer should review the requirements to assure they are complete and not contradictory. Local laws may require special requirements for hurricanes, earthquakes or other public safety issues.

The base rules for piping engineering are the ASME B31 Codes (herein referred to as the Codes). Each Code provides the typical loading conditions to be considered; allowable stresses; minimum wall thickness calculations; and minimum fabrication, inspection and testing requirements. Other major codes are listed that may apply in certain situations. This is not an all-inclusive list

- o B31.1, "Power Piping", applies to electric power plant piping
- o B31.3 "Process Piping" applies to refinery and petrochemical plants
- o B31.4, "Pipeline for Liquid Hydrocarbons and Other Liquids", applies to underground liquid pipelines
- o B31.5, "Refrigeration" applies to major refrigeration systems, as might be found in food processing plants.
- o B31.8, "Gas Transmission & Distribution Piping Systems" applies to underground gas transmission lines.
- o ASME Boiler and Pressure Vessel Code applies to boiler supplied piping.
- o For pipelines, there are Department of Transportation requirements that may apply, such as CFR Part 192
- o For modifications to existing plants, OSHA 1910.119 may apply to Management of Change, Mechanical Integrity and Inspection Requirements.

Depending on the plant location and the type of facility, it may be legally mandatory to comply with ASME and other codes. Even if there is no legal requirement, the client, and insurance underwriters may require compliance/with ASME codes. And at a minimum, good engineering practices should be followed that are described in the Codes.

If a facility is outside the United States there may be a set of international Codes that are prescribed.

In most plants, one piping code applies to all piping systems, but sometimes it is not appropriate to take this approach. A petrochemical plant may be designed to B31.3, but there may be a power boiler supplying power, and that piping should be designed to B31.1 and parts may be designed to ASME Boiler & Pressure Vessel Code. Pipelines designed to B31.4 and B31.8 may change to B31.3 when brought out of the ground for a compressor station or processing facility.

In the history of the B31 Codes before the 1960's, all facility pipes were covered by one code. As plants became larger and more complicated, the attributes of typical plants lead to different loading conditions, and different methods of defining safety factors. If all pipe rules had been left in one Code, it is likely that undue conservatism would have been applied to large numbers of pipe in order to create a Code that "One size fits all." Some of the driving factors to different approaches include:

o Power piping is focused on high pressure and high temperature water and steam with very few chemicals. The plants tend to be vertical, which creates high thermal vertical movements that must be accommodated by spring supports. Plants are usually away from residential areas and the potential for damage to nearby landowners is typically insignificant.

o Petrochemical plants typically operate at much lower pressures and temperatures than power plants, but the various chemicals result in corrosion issues, and the use of many special alloy materials. These plants are also laid out horizontally with most pipe supports being rigid on pipe racks. Plants are often in large industrial areas. If there is a fire or explosion, there is always a concern in minimizing the damage to the local area of a plant or unit within a plant. Explosions may release hazardous chemicals in the air or in water, and thus mechanical integrity must always be a primary design criterion.

o Pipelines are typically underground with no thermal considerations. The pipes are not put in bending at supports, and thus design rules allow thinner pipe for the same pressure compared to B31.1 and B31.3. Pipelines may be in unpopulated areas, or running through suburban and urban areas. Because of the potential for damage to nearby landowners, rules are different based on the pipe's proximity to populated areas.

There are a number of similarities in each Code, such as in the calculation of minimum wall thickness, inspection and testing. But the exact rules are different, depending on the type of facility. Allowable stresses are different in each code, reflecting a different factor of safety based on the expected use and operation of the facility.

The Codes contain some rules and minimum standards, but for the most part, they provide guidance and items to consider. For example, B31.1, says the "Design shall consider seismic events" but it provides no methodology to perform the calculations, or even a design basis to create the seismic loads.

Since the Codes provide minimum acceptance levels based on simplified approaches, more rigorous analysis, inspection and testing methods can be applied when appropriate.

The Codes are design codes and are generally not intended for maintenance and operation of piping systems. In the past few years some non-mandatory appendices have been adopted concerning maintenance, and B31.1 has added a mandatory maintenance and inspection Chapter for high energy piping systems in plants designed after 2014. API has several Recommended Practices for inspection and evaluation of piping, such as API 570, 574, 579 and 580, which are usually applied to Process Plants.

Once a Code has been selected to apply to a particular piping system, only that code should be applied. For example, it is not allowed to use a minimum wall thickness calculation from B31.3, an allowable stress value from B31.8, and an inspection method from B31.1. While it appears obvious that we cannot "cherry pick" the aspects we like from each Code, there are many times that the Codes are incomplete or give no guidance for certain conditions. In these situations it is appropriate to research other codes, technical papers and other published documents for guidelines to properly engineer the piping system. With this information, a rational engineering judgment can be made that is at least as conservative as the governing Code.

Other standards that are often referenced in piping engineering are:
- American Petroleum Institute (API) maintenance and inspection of piping components
- Manufacturer Standards Society for pipe supports, MSS-SP-58 AND MSS-SP-69
- American National Standards Institute (ANSI) for various piping components including valves, fittings, and radiographic plugs.
- American Standards Testing Manufacturers, materials, inspection methods, testing methods
- American Welding Society
- American Water Works Association
- National Fire protection Association

The rules and guidance in the Codes and standards are based on experience, laboratory tests, theoretical stress analysis, and good engineering judgment. Those who practice piping engineering must understand the applications of the rules, and be cognizant of

types of fabrication, loading conditions and other factors that need to be considered in each piping system.

As with most Codes, rules and guidelines, there is almost no method to adequately provide rules for all possible loading conditions, piping configurations and applications. Even the most experienced piping engineers must consider the loading conditions that could apply to each piping system to assure that everything reasonable has been done to assure "It is safe for you to stand next to that pipe."

2.2 Loading Conditions

Defining the appropriate loading conditions to be applied to each piping system is often the most difficult portion of the work. As will be clear in the later discussions, the routing of the pipe and the types of pipe supports and other considerations are based on the loading conditions. It is imperative that the loading conditions to be considered and the magnitude be defined before starting the detailed design. Otherwise, detail design may be a waste of time, and may lock in design constraints that cannot be resolved.

The loading conditions can be split into two groups, static and dynamic. The static loads also have a transition loading as pipe moves from one condition to another, but in most cases, the transition loading is not separately considered, unless it is so rapid as to be a dynamic load. Dynamic loads may be design requirements, such as safety valve thrust, but they may also be conditions that need to be avoided by proper engineering of valve operating speeds, proper draining, fluid velocities or other considerations.

Static Loading:
a. Temperature – may be multiple operating temperatures and temperature cycles.
b. Pressure – may be standard operating pressure, upset condition pressures and design pressure
c. Equipment Movements – typically related to the thermal movement of the pipe as the equipment heats up and cools down. Equipment movement must also be considered in wind and seismic loading conditions.
d. Dead weight, to include pipe, fluid, in-line components, insulation, branch lines, pipe support attachments, and any other attachments.
e. Wind – while this is technically a dynamic condition, it is usually analyzed as an "equivalent static" condition.
f. Cyclic conditions created by "batch" operations in which a pipe may be alternately filled and emptied many times a day. Depending on the process, this may need to be considered a "static fatigue" such as thermal, or a Dynamic Loading Condition.

Dynamic Loading:

g.   Steam hammer created by sudden closure of valves creating pressure waves in the pipe. These are typically very fast acting valves at 0.5 to 0.05 seconds, installed to protect turbine generators from over speed conditions.

h.   Surge or pressure waves caused by opening or closing in-line valves. This condition is differentiated from steam hammer, as this situation is often in pipelines, or other long pipes in which it may take minutes to establish or stop flow. If the valves operate too quickly, large unbalanced pressure forces can create a "surge".

i.   Thrust created by safety valve, rupture disk or other devices openings for pressure relief of a system.

j.   Water hammer or other condition created by two phase flow. There are multiple definitions of water hammer, but some of the worst conditions are created by high temperature steam suddenly impacting water in a pipe. The sudden flashing of water to steam can be so great that there is no practical way to design for the loads. The engineering solution is to avoid the possibility of such a situation.

k.   Thermal shock from rapid cooling or heating of a pipe surface. Again this situation should be avoided by proper design, as most materials will crack and fail from thermal shock.

l.   Seismic event

m.   Pipe whip created by sudden fracturing of a pipe. This is a nuclear power plant consideration and not discussed in this course.

n.   Various upset conditions that can be created by an out of control chemical reaction. The usual consideration is temporary high temperature and/or high pressure operation. Depending on the transition speed during the upset condition, this might be analyzed as a static loading condition.

o.   Various upset conditions that can be caused by loss of controls to valves and other devices that may cause a sudden fail close or fail open condition that can create the pressure waves and thermal shock conditions.

p.   Flow induced vibrations can be created by various sources. A reciprocating compressor discharge pipe must be specifically designed with "bottles" to dampen the vibration.   Other sources of vibrations can be pumps, cycling valves, batch operation or multiple sources of fluids that may be mixed together. Except for the reciprocating compressor issue, rarely are flow induced vibrations analyzed, but reliance is made of using appropriate "Rules of thumb for velocities in pipes. If problems are observed in the field, then remedial methods are used.

2.3   Equipment Requirements

The interface between pipe and equipment is extremely important and must be properly managed throughout the design process.

➢ Location, size and type of each nozzle on the equipment match the piping design.
➢ Design conditions (temperature and pressure) are consistent with the pipe.
➢ Safety valve set pressure is set to be consistent with the pipe operating conditions.
➢ Equipment nozzle movements due to temperature can be accommodated by the pipe flexibility and supports.
➢ Loads applied by the piping on the nozzles are acceptable to the equipment manufacturer.
➢ If the equipment manufacturer insists on expansion joints at the nozzle, is the pipe routed, and the pipe supports arranged to make this acceptable?

Equipment manufacturers are primarily focused on producing a product that will do its job, i.e. a pump that creates the correct head and flow rate over the operating conditions, vessels that create the correct internal chemical reactions, etc. Pipe connections are necessary, but are not the vendor's focus. Over the years, some manufacturers have developed standards that are so thoroughly focused on minimizing the loads from pipe, that it is almost impossible to meet the required loads. One of the best protections for proper piping engineering is to set reasonable allowable loads in the Request For Proposal for rotating equipment. Vendors can often accept higher loads safely, but they need to understand the requirement when the request for equipment is first made.

There is a second set of equipment requirements that is discussed in the Section, "System Approach". Some vendors provide piping on a skid or as part of their equipment that connects to the remainder of the plant piping. The piping on the equipment must be considered as part of the piping system in all loading conditions. Depending on the situation, this can be a difficult process to manage technically, and contractually.

2.4   CLIENT / PROJECT PREFERENCES

It is expected that a client that is paying millions or hundreds of millions of dollars for a plant has specific features that are desired. Most of these preferences are focused on equipment performance. However, there are often preferences on types of valves, plant arrangement, valve manufacturers, material specifications, corrosion allowance and even pipe supports.

The piping engineer should have a discussion with written direction on each of these preferences prior to starting design. Discussion should also focus on general approach to

design, what the deliverable drawings will look like and contain, and specifics on all components. Keep these discussions going as detailed design decisions are made.

Often acceptable designs are considered unacceptable by the client because these preferences were not properly discussed and agreed to early in the process. Likewise, sometimes client preferences are based on an individual or group's experience that has little to do with the current design. This leads to some dictates such as "No spring hangers", "Install expansion joints on every pump suction and discharge nozzle", or other requirements that waste client money, make the design very difficult to develop and actually make the design less safe. Sometimes clients will listen to logic, and sometimes they can adequately explain the reason for their preference, but sometimes long term client dissatisfaction with an engineer is created by such arbitrary rules.

2.5   Material Specifications

The selection of the proper materials is a complex task that must occur before detail design begins. This is even more important now than in the past, since most major pipe is designed using 3D modeling techniques, and the model is specification driven.

These specifications may derive from client standards, a design engineering company's standards, a previous project or even a standard industry database. No matter the source, it must be carefully checked to assure it matches the requirements for this particular project and service. Older specifications may be out of date due to changes in Code requirements, changes in valve manufacturer available models, and changes in standard available pipe sizes and fittings.

Some standards allow multiple choices for certain components, such as flanged or butt welded, socket welded or flanged, multiple choices for valves, and multiple choices for inspection and testing. It is strongly recommended that choices be limited before beginning design. If there are different requirements for different systems, create more material specifications. This reduces confusion at the design, engineering, material purchase, fabrication and construction steps in a project.

If there are critical chemical requirements that can create corrosion, assure a metallurgical specialist reviews the specifications in detail. Assure all components are reviewed, as the pipe may be correct, but if the wrong gasket is specified the pipe may still leak.

Method of pipe manufacture can be important in the long-term reliability of a system. In particular, seamless pipe is usually preferred over seam welded pipe for reliability and safety. When a seamless pipe fails at a circumferential weld, typically a crack opens up in one portion of the weld around the circumference. Usually, this opening relieves some

of the stresses that are propagating the crack, limiting the opening size. Obviously this can still be a dangerous situation, but the leak is "limited". In a seam welded pipe, if a crack develops in a seam weld, it can propagate the full length of the seam weld between circumferential welds. This is referred to as a "catastrophic failure" and results in a "nearly total, instantaneous release" of the contained fluid.   Large diameter pipes are expensive to purchase in seamless configuration, and thus seam welded pipe is commonly supplied.

FIGURE 2.1 SEAM WELDED STEAM PIPE FAILED BETWEEN TWO GIRTH WELDS, INJURING 15 PEOPLE
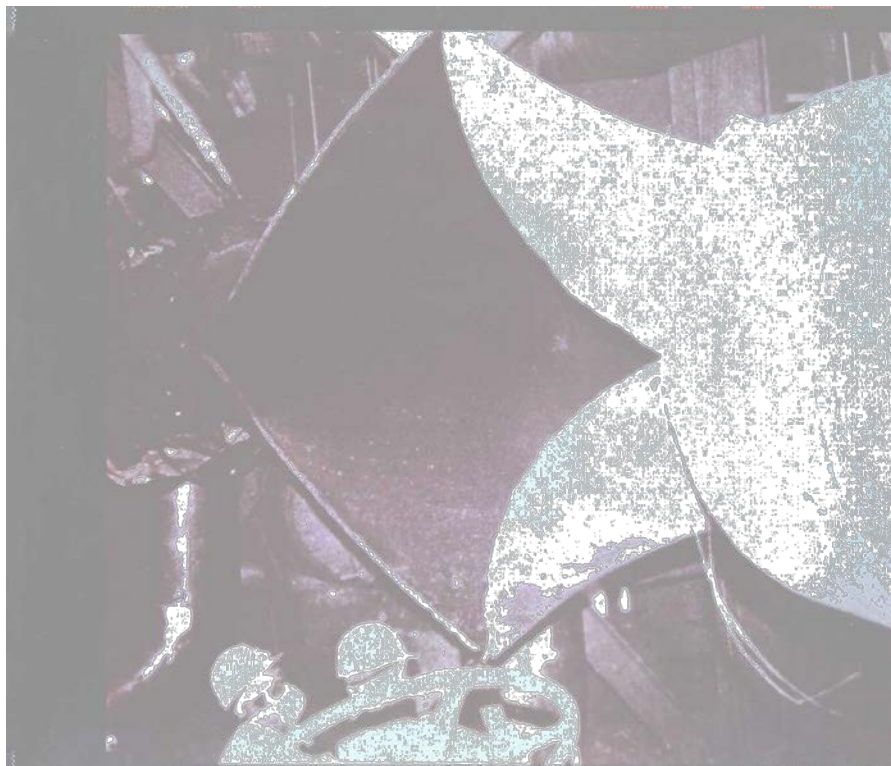
One issue that seems to continually cause confusion in material specifications is the design conditions, primarily the design and operating temperatures and pressures. Material specifications are typically split into classes based on type of material, pressure and temperature. It is common to see materials that indicate a group of materials are adequate from -20F to 600F up to 700 psig, and the next group of materials is satisfactory from -20F to 600F and 1200 psig. This is all very reasonable to minimize material costs as the largest possible group of standard materials is ordered.

However, there can be a serious misunderstanding when individual piping systems are considered. Table 2.1 shows three line numbers all designed to material specification A1. Each line has a completely different set of operating and upset conditions for design.

When engineering a system, the line design conditions should be used for analyzing for thermal conditions. Just because a material specification is satisfactory for all components at 600 psig @ 650F, does not mean that the piping system should be engineered for the maximum material specification temperature. If so designed, it would be a large waste of money in designing pipe and supports to conditions the piping system will never experience.

Unfortunately some practitioners have applied the material specification values in a line list for the operating and /or design conditions. This practice should not be done. When performing retrofit work, it needs to be recognized that the existing design and operating conditions on a line list may not represent the conditions the piping systems were engineered for.

TABLE 2.1 EXAMPLES OF DESIGN CONDITIONS

LINE NO.	MATL LIMIT	NORM. OPER TEMP, F	NORM. OPER PRESS, PSIG	UPSET TEMP, F	UPSET PRESS, PSIG	LINE DESIGN TEMP, F	LINE DESIGN PRESS, PSIG
A1-ST1	600 PSIG @ 650F	450	300	500	350	500	360
A1-CO1	600 PSIG @ 650F	210	50	250	90	250	100
A1-ST2	600 PSIG @ 650F	625	580	NA	NA	640	600

2.6   FAILURE MODES

In every piping system there are multiple potential failure modes. As noted initially, most piping systems operate decades with little or no damage. But of those systems that have failed, usually they have root cause(s) in which some basic fundamental issues were not adequately understood, considered, and/or designed for.

> **A special caution for plant modifications: A system that is modified needs to be completely reconsidered, even if only a small section of**

pipe is being replaced. The assumptions that may have been entirely appropriate for the original design may be violated by what is seemingly a minor change. Most petrochemical plants have a formal Management of Change (MOC) procedure to consider these issues. The procedure is extremely important. If an engineer is working on a plant without a formal MOC approval procedure, the engineer should assure that the entire piping system is still acceptable when a design or operational change is being made.

In other sections there are discussions of corrosion, thermal, pressure, and dynamic loading conditions that need to be evaluated. Some of the other failure modes that should be considered include:

1. Velocities of fluid are extremely important in determining whether a piping system will erode. In fluid conditions, velocities of 15 feet per second in straight pipe, is a general standard. However, every change in direction, reducer or branch will locally accelerate the flow. Some major failures have occurred when multiple components were tied together, (a branch to a reducer to an elbow) and the pipe eroded when the local velocity was more than 3 times greater than expected. One of the industry solutions has been to use a hardened material, such as a chrome-moly alloy to reduce the erosion at locations that might be susceptible.

Steam and gas velocities are usually an order of magnitude greater than fluid flow before any concern of erosion exists.

2. Hardened pipe is often also specified on systems such as condensate drains in which two phase flow may be expected. This failure mode is often described as Flow Accelerated Corrosion (FAC) in which the corrosion layer is removed by locally high fluid velocity; the corrosion layer is re-established and then removed again by the fast moving fluid. Over time, the corrosion reestablishes and is then removed again, eventually creating very thin pipe in local areas around bends and branches. Using chrome-moly pipe has been found to virtually eliminate the FAC failures.

3. At low temperatures, embrittlement of normal steels can occur. Special low temperature alloys need to be specified.

4. At high temperatures (above 800F for carbon steel and higher temperatures for certain alloys) creep damage can degrade the pipe. Creep is a time – stress – temperature dependent process that creates voids in the grain boundaries and has been the root cause of some of the worst piping failures in power plants.

5. A special consideration for high temperature pipe. Catastrophic failures have occurred in seam welded high temperature pipes due to creep degradation, high stress intensification at the seam weld and other issues. Many studies have been performed by the Electric Power Research Institute (EPRI), Materials Properties Council (MPC), and other organizations, to determine the root causes of high temperature seam welded pipe failures. While knowledge and understanding has been advanced, there is not a set of exact root cause(s), and design recommendations have never been achieved. Large numbers of these pipes have been replaced with seamless pipe because the industry is not capable of guaranteeing the condition of seam welded pipe.

> **Seam welded pipe should not be specified for installation in which it will be operating in the material's creep range. The long term strength of the pipe cannot be adequately analyzed and assessed based on information available today. If seam welded pipe is used in such applications, Owner must understand that 100% inspection should be performed periodically over the life of the system.**

6. Embrittlement can also happen at high temperatures when hydrogen in the fluid travels in the grain boundary and creates hydrogen embrittlement. Depending on the material and fluid, this can happen at relatively low temperatures or high temperatures.

7. Dissimilar metals welds can cause failure in piping systems. At times, it was common in the industry to install stainless steel thermowells and other components in carbon steel or alloy piping systems. As experience has found, any dissimilar metal weld that operates at elevated temperatures, can be susceptible to thermal cracking. Dissimilar metals may have different thermal expansion rates. Even on small welds, with time cracking may develop and installed components such as thermowells, have been known to "shoot out of the pipe." Dissimilar metal welds can be safely made using the correct weld material and base materials, but they must be selected with care.

8. Any component inserted into the flow has the potential to create vortices that can create vibrations and fail the component.   This is called vortex shedding and improperly designed components can break off. One example is a thermowell inserted into the flow.

9. Branch connections in high flow can also create vortex shedding at the opening. The result is often an audible "whistling" and can result in erosion of the nozzle, and ultimately failure. The design solutions usually are to reduce the flow rate locally in the area of the branch, and to round the contour so that there are no sharp edges.

3.0   SYSTEM APPROACH

All piping systems are engineered to transport a fluid or gas safely and reliably from one piece of equipment to another. The system may be easy to define as the pipe and supports from one pump to a tank or multiple pumps to multiple tanks. However, there are almost always other pipe branches in a system for drains, vents, safety relief, introduction of chemicals, extraction for other purposes, etc. It is also necessary to include all pipe supports in the definition of a piping system, as the design and functioning of these supports have a great deal to do with the reliability and safety of any piping system.

Sometimes system boundaries are confused by contractual limits. For example, if a skid mounted pump is supplied with several feet of pipe by the skid supplier, and a different engineer ties in to route the pipe to a tank, "What is the end of the piping system?" From an engineering perspective, the system is still from the pump to the tank. The coordination and political issues may be more difficult when multiple vendors are designing one piping system, but it is imperative that one entity have responsibility to assure the entire piping system has been engineered properly.

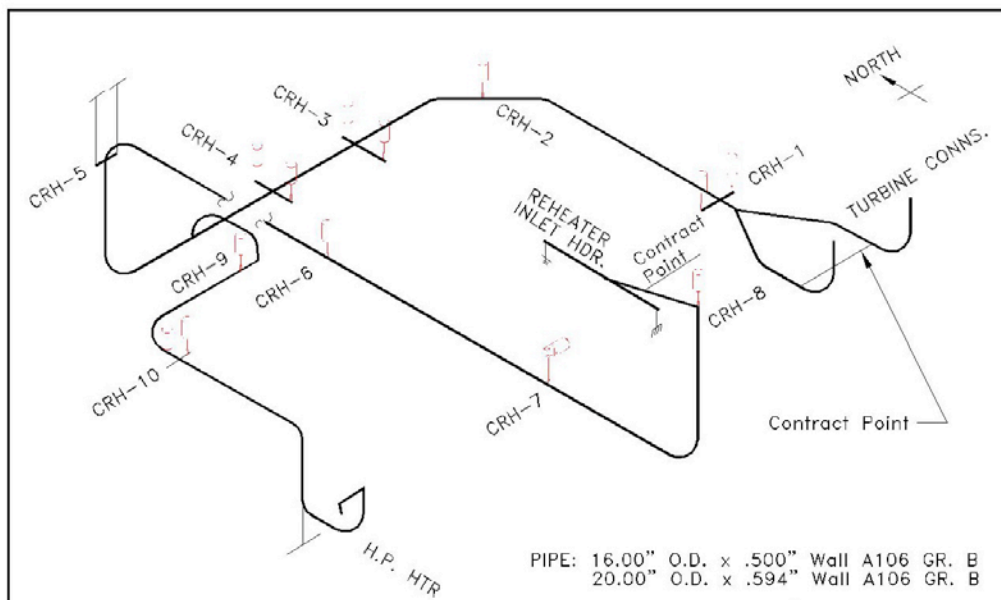**FIGURE 3.1 ISOMETRIC OF PIPING SYSTEM SUPPLIED BY 3 ORGANIZATIONS**

Fig. 3.1 depicts an even more complicated scenario in which a boiler and turbine vendor supply some of the pipe that is primarily engineered by the Balance of Plant Engineer. In

these cases, both equipment pipes must be analyzed with the connecting pipe, and the pipe supports properly sized for the system.

A major consideration is how to consider branch connections on a piping system. A general rule of thumb is "Include all branches in the analysis if the ratio of the mainline section modulus to the branch line section is less than a factor of 7. The logic is that if the branch line is much smaller than the main line, then the small line cannot significantly affect the main line. One exception is if the small line is supported such that it restricts the movement of the main line.

The consideration of branch connections and equipment piping can be difficult when evaluating static loads. If dynamic loads are also significant, then the coordination and analysis issues are multiplied.

Sometimes it is impractical to include all of the piping system in one analysis because of the timing of the design and construction, the number of branch lines, or the complexity of multiple design conditions. A method that is commonly used is to install an anchor in a piping system. (See Section 6 for the definition of an anchor.) The pipe on either side of the anchor can be analyzed as totally separate systems. There are often advantages to this approach in limiting pipe movement, controlling the number of design conditions, and even in limiting pipe support loads and pipe stresses. If it is expected that future branch connections will be added later, it is a great benefit to locate an anchor on the pipe near this branch point. It will facilitate the future design and engineering.

If a support is included in the analysis, then it
must be designed and installed in the piping
system to match the analysis.

This rule seems so obvious that it should not need to be stated, but due to poor communication between piping engineers, designers and structural engineers, this fundamental rule has been violated an amazing number of times.

4.0　ENGINEERING FOR STATIC LOADS

4.1　Pressure

Depending on the normal service conditions, possible upset conditions, types of equipment it is connected to, and external sources, there are a number of possible pressure loading conditions that need to be considered, and the pipe engineered to contain the fluid safely and reliably.

Virtually every pipe must contain an internal or external pressure. Internal pressure is defined as: "The pressure inside the pipe is greater than the external pressure around the pipe." This is the most common occurrence and the rules in the B31 codes are very specific on the rules for calculating minimum pipe wall thickness.

When pressure is applied to the inside of the pipe, there are two primary stresses created,
　　Longitudinal Pressure Stress $= S_{lp} = Pd^2/(D^2 - d^2)$
　　Where P= Design Pressure
　　D= Outside Pipe Diameter, nominal
　　d = Inside Pipe Diameter, nominal
　　S = Allowable Stress at design temperature
　　E = Quality factor based upon fabrication technique and /or inspection quality
　　y = Design Factor for temperature
　　CA = Corrosion Allowance
　　(Ref. B31.1, Section 102.3.2)

The other Codes have slightly different variations on this same equation.

S_{lp} is the stress created attempting to pull the pipe along its length. As shown in Figure 4.1, the pipe is pulled apart along its length, and each of the formulas approximates the stress in the pipe along its axial direction.

An analogy that is often useful to consider is a fire hose. When the valve is opened the hose may jump and move violently on the ground as flow is established. This hose movement is caused by an unbalanced pressure force, in each length of the hose, as the flow is initiated. Once a steady state flow is established, the hose is stable as all pressure forces are balanced by the forces at all the other bends in the hose.

At the hose nozzle, there is a sudden pressure drop from the hose pressure to near atmospheric pressure, and the nozzle must be restrained or it will swing around in an unpredictable pattern. This hose analogy will be used in discussing some of the dynamic loading conditions and expansion joints.

FIGURE 4.1 PIPING SYSTEM PRESSURE STRESSES
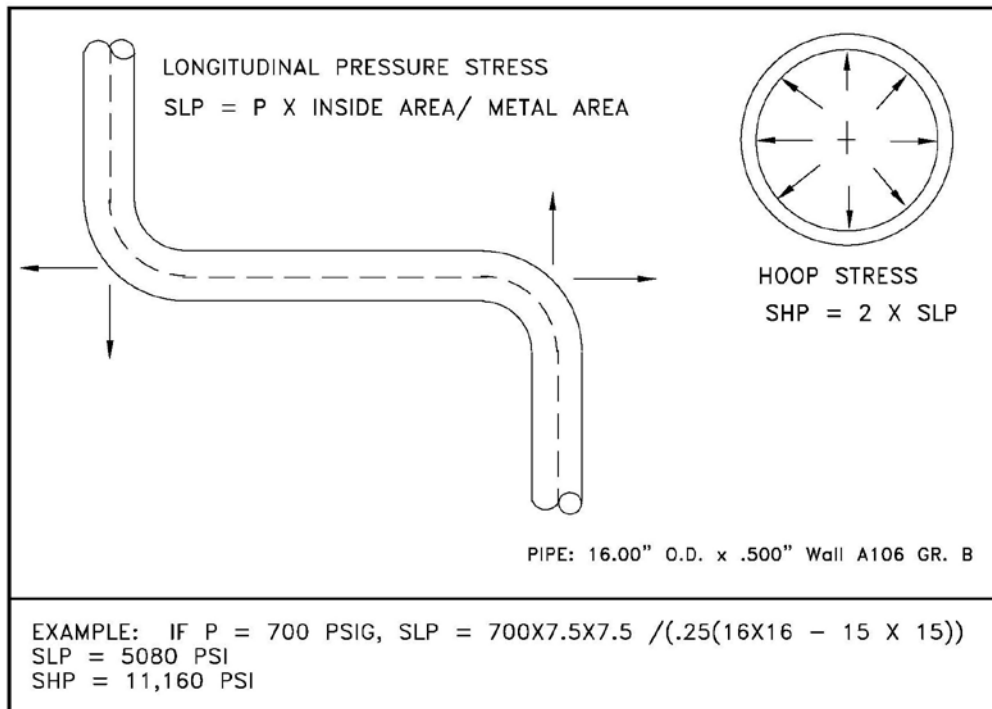
The second pressure stress is the Hoop Stress, which is created by the pressure expanding the pipe circumferentially. The hoop stress is approximately twice the longitudinal pressure stress. Except for ASME B31.8, the Codes do not specifically calculate the hoop stress. Instead it is included in the method to calculate the minimum wall thickness, t_m.

$$t_m = (P\,D/\,2\,(SE+Py)) + CA$$

The equations again vary somewhat between the Codes, but the basic equation is similar.

These wall thickness and longitudinal pressure stress calculations appear straight forward, but there are important considerations.

Design Pressure may be set based on different criteria:
- Set at the maximum expected operating pressure, or perhaps the operating pressure plus 3% to 10%. Most safety valves can be set at 3% to 10%

accumulation and this factor matches the Design Pressure to the safety valve release pressure.

- Set at the design pressure for a group of standard materials. For example, there may be a standard carbon steel material set up for all pipe operated up to 500 psig. While the operating pressure may be only 100 psi, the system design pressure may be 500 psi. This system makes the purchase and control of materials much easier than creating a different material specification for relatively minor changes in pressure.
- There may be an upset condition that the pressure (and temperature) can temporarily spike above normal operation. Both B31.1 and B31.3 allow temporary loading conditions for minutes or even hours at these higher conditions. If the event pressure spike is small enough and short enough duration, then perhaps the design pressure does not have to be increased. But if either time or magnitude limits are exceeded, the design pressure must be increased to assure the pipe design meets Code requirements. Note that B31.4 and B31.8 do not have this temporary upset limitation.
- Maximum pressure may be set by equipment limitations, such as the dead head pressure of a pump, or the maximum allowable pressure in an attached pressure vessel.
- Maximum pressure may be set by in-line or attached equipment pressure limitations, such as the maximum allowable pressure on a valve.

Corrosion Allowance (CA) is often defined by the owner. CA should be based on the environment that can create external corrosion, and the fluid that may create internal corrosion and /or erosion. Typical values are 0.0" for superheated steam systems, to 1/32" to 1/8" for chemical systems.

External pressure on pipe exists on a small percentage of piping systems. In some cases the pipe may typically be subjected to external pressure, but an upset condition can create a vacuum that can collapse the pipe. None of the B31 Codes provide rules for calculating minimum wall thickness and reinforcement for this condition. Typically, thickness calculations are made by referring to the ASME Boiler and Pressure Vessel Code, Section VIII, Section ULT. This section defines calculations for pressure vessels subject to a vacuum pressure, and the equations can be adapted for pipes.

4.2 Temperature

When a material is heated, it expands. B31.1 and B31.3 contain Tables in the Appendices that define the expansion rate for most metals. These are averages based on classes of materials. For most steels, a useful approximation is

Expansion in inches/ 100 feet of length = (Oper Temp – 100)/100.

For a pipe operating from an ambient temperature of 70F to an operating temperature of 1000F, a 100 foot length of pipe will lengthen approximately (1000-100)/100 = 9", and a line operating at 500F would expand 4" over 100 feet. The more exact values provided in the codes should be used in any detailed calculations.

This thermal expansion is absorbed in the pipe by bending at elbows, branch connections, and other changes in pipe direction. The temperature differential creates pipe stresses that must be maintained within allowable limits, creates thermal loads on pipe supports, and creates loads on equipment. See Figure 4.2 for an example of movements in a piping system.

FIGURE 4.2 EXAMPLE OF PIPING SYSTEM THERMAL MVOEMENT
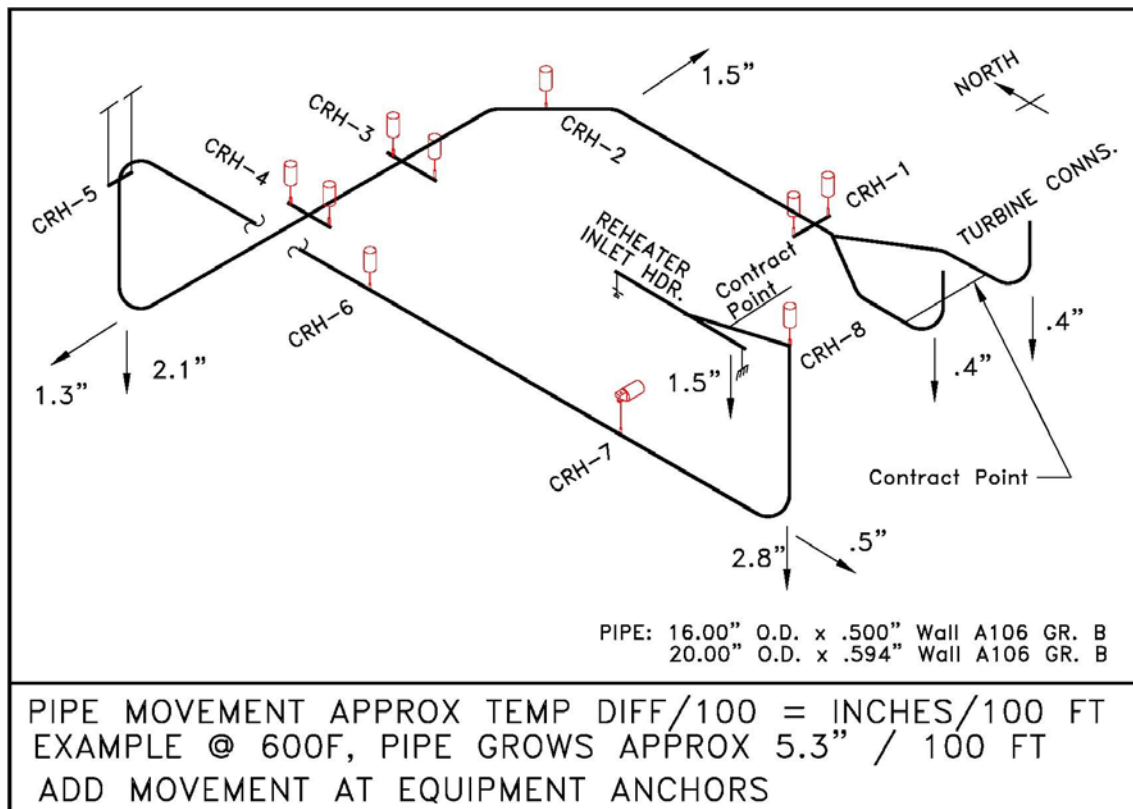
Pipe with any significant temperature difference from ambient should be routed with some changes in direction to relieve the pipe stresses. If pipe is routed straight, such as from a pump discharge to a tank wall, the axial stresses would probably be so excessive that cracks will develop in the tank wall connection, or overload the pump nozzles.

Thermal stress in the ASME codes is considered a fatigue stress and the allowable pipe stress is specified as a stress range. The change in stress at ambient temperature to the operating temperature is the stress range, and the allowable is based on the number of expected cycles. This is the definition of a "Secondary Stress", in which the pipe may self stress relieve due to thermal loading.

Most equipment manufacturers provide allowable loads on their nozzles that should not be exceeded without specific approval by the vendor. In most cases, the equipment allowable loads will be a more critical design factor than the stress range allowable in B31.1 and B31.3.

4.2.1   Cold Spring

ASME B31.1 refers to cold spring and it may be proposed by some people to solve a thermal expansion issue on pipe. Cold spring is the intentional cutting short of pipe lengths so that a load is induced on equipment in the ambient condition, and when the pipe heats up, the force and moment on the equipment nozzle is 0 pounds and 0 foot pounds. On the surface this sounds like a good idea, but most engineering companies do not allow the use of cold spring in the analysis and design for a number of reasons, as follows:

1. The Codes compare calculated thermal pipe stresses to the range of stress. The calculated stress range does not change no matter how much cold spring is incorporated in a design.
2. The theory is that by cutting each pipe length short, the loads on the equipment will be exactly countered by the thermal growth. This is a very simplistic view of the pipe, because there are usually rigid supports, spring supports, guides and other devices which affect the loads. To determine how to arrange each of these supports during erection and after final welding to achieve the goal of cold spring is virtually impossible.
3. Even if objection 2 could be overcome, pipe is erected from equipment to equipment, and eventually all the cold spring is centered on one weld in which the pipe must be pulled together to make a weld. It is almost impossible to pull the pipe and create the loading comparable to the loads created in the thermal heat up and cool down.
4. High temperature pipe will relax with time. After 3 or 4 cycles, the pipe will probably relax to a position similar to the theoretical cold pull position, without going through all that effort.
5. Pipe fabrication and erection is an inexact process. Pipe fitters can and will adjust rotations at welds to make the pipe fit to the next weld. As usually happens, the fits are not perfect, and some pulling of the pipe is necessary. If the pull is minimal, then

usually it is acceptable on the pipe stress and equipment loads, particularly if there is no cold spring. However, if a pull is already set for several inches, and then more pulling is necessary, the welding may have to be re-done because the pipe is too far out of tolerance.

4.2.2 Expansion Joints

It is somewhat common to hear requests from non-piping engineers to take care of all the thermal issues by "Just add some expansion joints." Occasionally expansion joints are the most efficient solution, but that is only in specific cases. In general the use of expansion joints should be considered a last resort.

Expansion joints are thin convolutions of metal or cloth that are installed in a piping system to absorb the thermal movement, and sometimes to try to isolate equipment vibrations. Should an expansion joint fail, fluid is released, which can cause a shutdown, collateral damage and injury to personnel. While such failures can occur in hard piping, they are much rarer than in expansion joints.

But the main problem with expansion joints is the number of design issues and costs that are associated with them.
1. Expansion joints must be limited to fairly low pressures, or else the pipe would literally pull apart at the expansion joint. There are some solutions described below, but the solutions tend to negate the effectiveness of the expansion joint.
2. Tie-rods, gimbal joints and other devices can be installed across an expansion joint to transfer the pressure from one side of the joint to the other without damaging the expansion joint. However, with tie rods the expansion joint has no flexibility in the axial direction, only in the angular and lateral directions, which greatly limits its effectiveness to absorb pipe movements.
3. If no tie rods are installed, then the pipe must be anchored, upstream and downstream to limit the axial growth of the pipe and keep the expansion joint from over expanding. Again, this limits its effectiveness to absorb movements.
4. There are strict rules on guiding expansion joints upstream and downstream to avoid damage from over rotation and squirm. Again this limits its effectiveness.
5. If expansion joints are designed with tie-rods and movement in all 3 directions must be absorbed, then often multiple joints must be installed.
6. Cost of an expansion joint is high compared with pipe, and each expansion joint must be maintained and inspected. Life expectancy is at best 10 to 20 years.
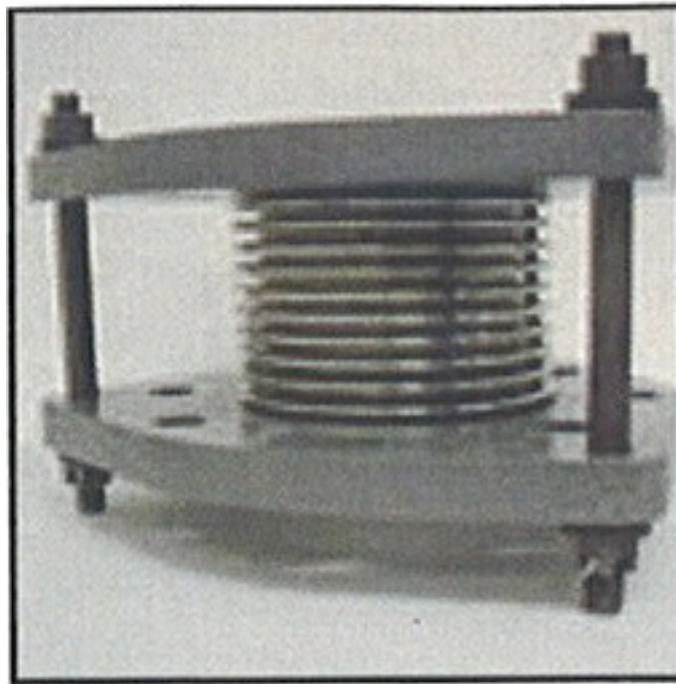
FIGURE 4.3 EXAMPLE OF METAL EXPANSION JOINT WITH TIE RODS

4.3 Dead Weight

Pipe weight is typically supported at point locations by either rigid or spring supports. The support locations should be based on criteria for sag, and for pipe stress. In most engineering companies and on the internet, support spacing tables are available based on the pipe size. These tables should be used with extreme caution, as in most cases, it is not clear what criteria for sag, insulation weight, pipe schedule, fluid weight and changes in pipe direction has been used to set the spacing. These tables are also usually missing necessary adjustment recommendations and criteria, such as the following:

1. Set spacing based on a maximum of 0.1" sag between supports.
2. Support all risers directly if greater than 15 feet in height.
3. If risers are greater than 50 feet in height, add guides every 30 feet.
4. Support all changes in directions such as elbows or bends within 3 pipe diameters of the end of a bend.
5. Support every major in-line component within 5 pipe diameters. This rule applies to valves, and other heavy components.
    a. See Figure 4.4 for examples of special branch components that are unusually heavy and would create pipe sag without nearby supports.

  b. In line components such as the WYE and lateral in Fig. 4.4, elbows, reducers and specialty components may have high stress intensification. To minimize dead weight pipe stresses additional pipe supports are needed near these components.

 6. Support all pipe attached to rotating equipment (compressors, pumps, turbines) within 3 pipe diameters if at all possible. In most cases use a variable spring support at the first location off the rotating equipment. This approach minimizes the load on the equipment nozzles, usually a primary concern.

If a pipe stress analysis is performed, it is usually found that these criteria are conservative, and spacing can be adjusted if supported by the analysis.
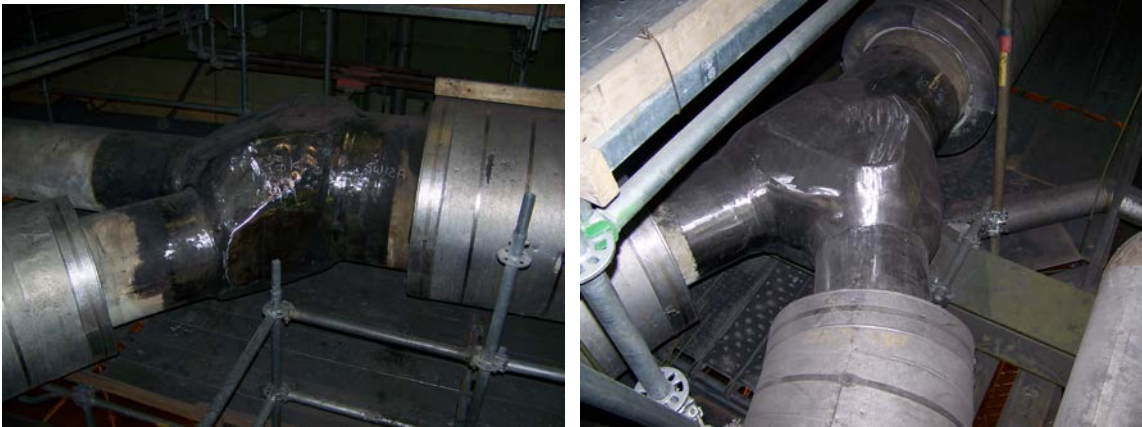

FIGURE 4.4 SPECIAL HEAVY WALL LATERAL AND WYE FITTINGS

Dead weight pipe stresses and longitudinal pressure stresses are considered static primary stresses. That is, stresses due to dead weight do not self stress relieve as do thermal stresses. The calculated stress of the dead weight bending with longitudinal pressure stress is compared to an allowable stress that is a percentage of material yield stress.

Pipe stress evaluation is not included in this introduction, but a general caution needs to be very clear to all involved. A stress analysis will provide stresses, loads and deflections for any system. When the distance between supports is extended to very long spans, the piping system may be unstable, but the calculated loads and stresses may appear acceptable. In evaluating any dead weight analysis, the following results should always be checked.

 1. Any conditions in which a pipe support is inactive. Load goes to 0 lbs or less. This most often occurs at rigid supports in which there is some thermal movement and the pipe tends to lift up off a support. While a 0 lbs load may be an

indication that this support is not needed; it may also mean that support types and locations of nearby supports need to be modified.

2. If there are any horizontal movements due to dead weight only that are greater than 0.25", it is a warning that the system is unstable, and additional supports and guides are needed. In virtually all the stress - strain formulas studied in textbooks, there is an assumption of small displacements. In the piping weight case, this limitation applies in the pipe stress analysis programs.

4.4   Wind

Wind on piping systems is generally not a serious problem. Recognizing that piping systems are outside and that wind can occur should lead to an automatic reaction that the pipe should be guided periodically for lateral loads created by the wind. Wind loading can be included in a pipe stress analysis program to assure that the supports are adequately sized for the expected loads.

5.0   ENGINEERING FOR DYNAMIC LOADING CONDITIONS

When dynamic loads must be accounted for, the pipe support / restraint system becomes much more difficult to design, particularly if there are significant thermal movements. In general, dynamic loads are restrained by various types of rigid supports. Often it is difficult to locate rigid supports on high temperature systems, and hydraulic snubbers, limit stops or other types of restraints are used.

Pipe stress is sometimes a criterion for acceptance of dynamic loads, but because of the very short duration of the load, the loads on the restraints and the movement of the pipe are usually the controlling criteria.

5.1   Safety Valve Thrust Forces

Any type of pressure relief device is included in this discussion, to include safety valves, relief valves, safety relief valves and rupture disks. All of these devices are specifically designed to release the internal fluid suddenly when the pressure exceeds a pre-set level. These devices are extremely important in protecting personnel and equipment from an overpressure situation, no matter what the cause.

In considering safety valve forces it is useful to re-consider the fire hose analogy. There is typically no flow at the safety valve branch. The flow is "dead headed" against the valve. As the valve opens, flow is established and there is a short term unbalanced flow in the valve and the downstream pipe. At the discharge point there is a large pressure drop, and often a large pressure drop in the safety valve also. This pressure drop creates a thrust force that may last for several minutes.

Thrust forces can be calculated by standard flow formulas. Most safety valve manufacturers calculate the thrust if the pressure, temperature and flow rates are set. ASME B31.1, Appendix II provides a detailed calculation method that can be performed by hand.

For the Piping Engineer, once the proper safety valve has been selected, and the thrust calculated, the problem is to determine the proper support. Under normal operation, there is virtually no load on the safety valve and its discharge nozzle. However, when it opens, very high stresses may exist.

The most common arrangement is shown in Fig. 5.1. The safety valve discharges into an elbow, and then into an open vent stack to atmosphere. The discharge elbow and vent stack are independent of each other. (The drippan shown in the photo is welded to the discharge elbow.) The thrust force operates downward through the elbow, and tries to

bend the safety valve branch off the pipe. Also, the pressure on the nozzle is at or greater than the pipe design pressure. These nozzles should generally be integral to the pipe and re-enforced. In high pressure applications, the standard branch design is not acceptable and special nozzles need to be designed, analyzed and installed.
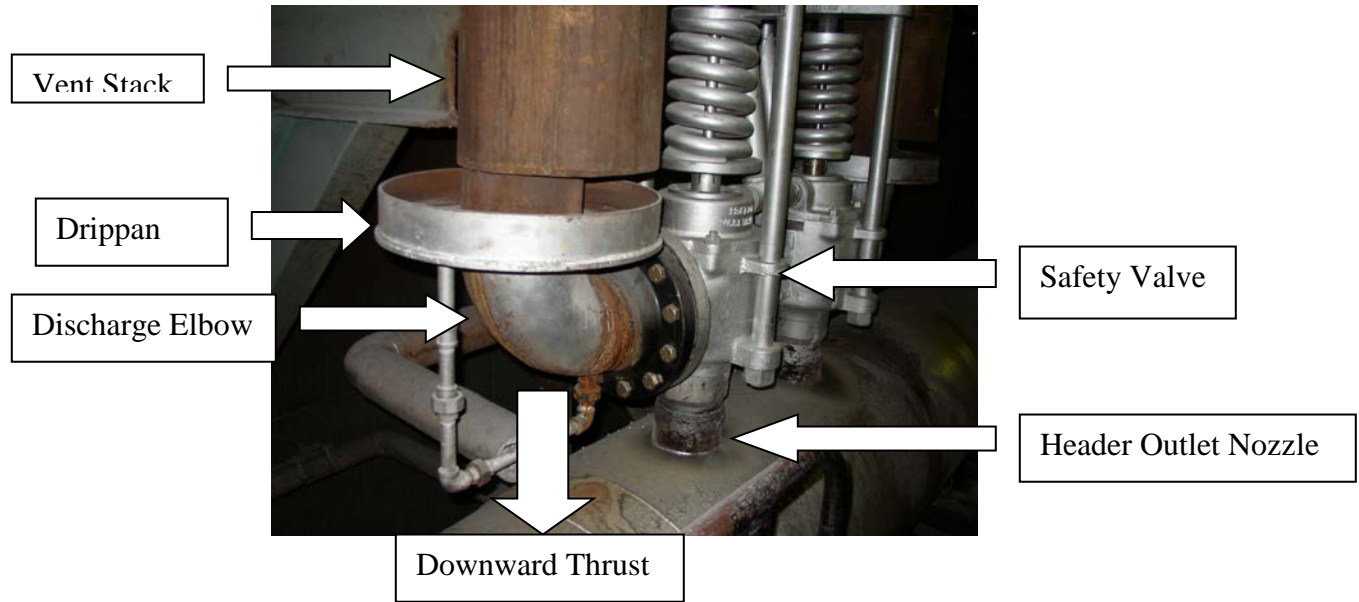

Vent Stack

Drippan

Discharge Elbow

Safety Valve

Header Outlet Nozzle

Downward Thrust

FIGURE 5.1 TYPICAL SAFETY VALVE INSTALLATION

Assuring the nozzle will not fail (and they sometimes did in the 1960s and 1970s before the criteria was well understood) is only part of the solution. The thrust force is now pushing down on the pipe, often with as much or more load than the dead weight load. The pipe generally must be supported to assure it does not deflect too far and fail supports, or create a high pipe stress away from the nozzle due to the thrust.

If thermal pipe movements are minimal and structural steel is available, then a rigid support, or set of rigid supports, can be installed at or near the safety valve nozzle. However, if there is a large amount of vertical movement, and particularly if the movement is up from ambient to operating condition, then specially designed limit stops or snubbers are required to adequately support the thrust load.

The vent stack pipe must also be adequately supported. Typically this is not too difficult as the thrust loads are much less than in the safety valve discharge nozzle, and the vent stack is not attached to any equipment. Vent stack pipe is usually supported rigidly in at least one location, and guided in multiple locations to control any lateral movement.

The top of the vent stack is often chamfered at an angle. A straight cut would make a very distinctive set of natural frequencies and modes of this pipe, which can be excited when the flow is established. By chamfering the outlet nozzle, the natural frequencies are made less distinct and vibration is rarely an issue.

5.2 Seismic

Engineering piping for earthquakes needs to be based on well thought out criteria and end goals. In the 1960s and 1970s, nuclear plants were being built and seismic considerations were a major factor in piping design. At the time, computer codes were not very sophisticated, and the seismic loading considerations were not well defined. Some of the nuclear seismic considerations were partially incorporated into fossil plants and even industrial plants. However, looking at these non-nuclear plants in hindsight, it is not clear what the goal was. Some major pipes are restrained, but other nearby pipes containing the same fluid, are not engineered for seismic events. Hydraulic snubbers must be maintained with hydraulic fluid and seal replacement to be operational. But many snubbers have obviously not been touched since installation.

Evans Goodling presented "Effects of Support Stiffness Variations on Seismic Inertia Stresses in Pipe" at the ASME1990 PV&P conference, (PVP Vol. 198), which brought a perspective to the entire seismic engineering situation. Some of the most important conclusions:
1. In an earthquake, pipe generally sways and moves due to the excitations, and this is the most efficient method to dissipate the forces.
2. Pipe in actual industrial applications, in the laboratory, and in detailed theoretical analysis does not fail due to earthquakes, with the following exceptions:
     a. A branch line is rigidly supported near the main pipe, and the movement of the main pipe damages the branch pipe or its support.
     b. Loads on restraints are exceeded, damaging the restraints.
     c. Pipe is excited by the seismic event and moves into another pipe, steel or other piece of equipment that damages the plant.
3. If seismic engineering is to be performed on piping, then the only two significant criteria are pipe movement and support loads.

If a plant is about to be designed, then the consideration of seismic must be considered per the Codes. Seismic analysis does not have to be performed if there is a rational consideration of the risks. Some of the questions that should be asked as the design basis is being developed are:

A. What is the seismic zone, and what is the expected level of activity?
B. Is there any fluid in the plant that if released would seriously injure personnel or neighbors?

C. Is there any fluid in the plant, that if released would cause serious, long term environmental damage?

D. If a seismic event occurs, does the plant expect to shut down, inspect the damage, repair as needed and then restart? Or is the expectation that the plant can run through the seismic event without shutting down? If the answer to the second question is yes, then there are a number of other systems besides piping that must be designed to very rigorous standards.

Based on the answer to the above questions, specific piping systems might be considered for seismic evaluation. In most cases, the number of pipes to be analyzed and the design costs can be minimized, by routing these pipes with the most clearance to other equipment, assuring adequate flexibility on each branch line and by judiciously locating rigid supports to minimize pipe movement.

5.3 Steam Hammer

Steam hammer is a term used to describe a pressure wave created in a steam pipe when valves are suddenly shut to protect a piece of equipment. Steam hammer is typically analyzed in large steam turbine electrical generating plants. If there is a sudden loss of load on the generator end of a turbine generator, very quickly an over speed condition can occur that literally tears the turbine - generator apart. To protect the equipment, large, very fast acting valves are installed on the steam inlet pipes. These valves may go from full open to fully closed, in 0.05 seconds. Any closing speed faster than 0.5 seconds should be analyzed for steam hammer loads.

Since the boiler cannot possibly be shut down this fast, there is a pressure wave from the turbine back to the boiler and a partial reflection wave from the boiler back towards the turbine. Dynamic loads on large power plant piping may be greater than 50,000 lbs, and these loads are created on every leg of the pipe as the pressure wave moves through. Since the pressure wave has a finite length, and thus a specific unbalanced pressure force, the forces are greatest on long lengths of pipe, and relatively insignificant on short lengths.

With today's computer models, a time history dynamic analysis can usually be performed to assess the displacements and support loads. Pipe stress is not a significant concern as the entire event may last 1 to 2 seconds. As with seismic, careful selection of support locations and restraint types can minimize the cost of restraining the pipe.

5.4 Water Hammer

Water hammer is a term used to describe several different flow - induced dynamic events. Almost all of these phenomena need to be avoided by proper pipe sizing, proper draining, correct valve sizing and valve speeds, and proper operation and maintenance.

For purposes of this course, the most serious water hammer is when a line contains water and is suddenly impacted by superheated steam. The flashing of steam to water can create a pressure wave of several hundred thousand pounds, move the pipe several feet and damage every support in a piping system. The solution is generally to assure no undrainable low points in a system, and to assure proper operation to open drain valves during startup and shutdown operations. This is also why on steam piping; designers usually build in a constant 1/16" to 1/8" per foot slope on all horizontal pipe legs.

5.5   Surge

Surge is crated by the startup or shutdown of a liquid system. The forces are dependent on the pressure, length of pipe, and the acceleration of the fluid. The practical consideration is usually long pipelines, and the best solution is to intentionally limit valve opening and closings to very slow openings, perhaps several minutes from fully closed to fully open.

5.6   Thermal Shock

Thermal shock is the sudden heating or cooling of metal. The sudden change in temperature can create a significant difference in the outside and inside temperature of a component, and thermal cracking. On large heavy wall components, such as boiler headers, large compressors and turbines there should be a limitation on the speed of heat up and cool down. If this is adhered to, then most pipes will not be harmed.

One other typical problem that must be avoided is the introduction of cold fluid in an existing operating system. This is sometimes done intentionally at a desuperheater (or attemperator), in which water is introduced into a superheated steam line to reduce the downstream temperature. If the fluid is properly atomized in a few feet, then the pipe is not damaged. However, if full atomization is not achieved, then the downstream pipe is susceptible to damage. Any systems of this type need to be carefully engineered for all expected operating conditions to assure thermal shocking can not occur.

6.0   PIPE SUPPORTS

There are a number of typical pipe supports that can be installed to support dead weight loads, and restrain the pipe for thermal and dynamic loads. While some typical supports are shown in these pictures, the designs are only limited by the imagination of the engineer and designer, as literally thousands of different designs have been used for special purposes.

There is often confusion created by mis-communication about types of supports between engineers, designers and the field. Following are the proper definitions that should be used. If there is any confusion in communication, assure that each person is thinking the same type of support when the term hanger, spring, anchor, etc is used. Photos of many of these support types are included after the definitions.

Pipe support: Global classification of all pipe supports and restraints.

Hanger: A vertical pipe support that incorporates a rod. It may be a rigid, variable spring or constant support hanger. Hanger is a term that often means quite different things to different people.

Variable spring support: Often called a variable spring hanger (VSH) by the suppliers. A helical coil that supports dead weight load. The support load changes as the spring moves through its range at a specified spring rate. This support can be a hanger above the pipe, or a floor support below the pipe.

Constant support hanger: A specially engineered hanger that is designed to travel through many inches of vertical travel with a minimal change in support load. There are different styles and types depending on the manufacturers. Per MSS SP-58 a constant support hanger can be within specification and still have a load variation of plus minus 6% through the travel range. Some suppliers claim a tighter tolerance on the load variation.

Rigid: Any type of support designed to allow no movement in at least one direction.

Rigid hanger: A hanger with a rod support.

Anchor: A rigid support that restricts movement in all three orthogonal directions and all three rotational directions. This usually is a welded stanchion that is welded or bolted to steel or concrete.

Axial restraint: A support designed to restrict movement down the centerline of the pipe. This is usually reserved to reference a horizontal pipe restraint.

Lateral Restraint (synonymous with Guide): A support designed to restrict movement of the pipe in a direction perpendicular to the pipe axis.

Hydraulic Snubber: A support with a piston and hydraulic reservoir designed to restrict dynamic movement, but allows nearly free movement due to thermal loads.

Mechanical Snubber: A support designed to restrict dynamic pipe movement by a mechanical device internal to the snubber. Mechanical snubbers were prone to failure that restricted pipe movement, and they are rarely found in use anymore.

Sway Brace: A variable spring designed to have no load in the center of the springs and restricts movement in either direction from the spring centerline.

Limit Stop: A restraint in any direction that allows a defined movement before acting as a rigid restraint.

Stanchion: A pipe support made of pipe that is welded to the pipe to be supported. Usually installed below a horizontal pipe.

Dummy Leg: A stanchion support attached to an elbow on a horizontal pipe. Commonly used on pipe in pipe racks to extend the support point to existing rack steel.

There are a myriad of methods of combining supports, such as a dummy leg with a rigid rod hanger, or an axial limit stop with a lateral restraint, etc.

As noted previously, whatever supports are assumed in an analysis, they must be included in the actual design.

Variable spring hangers, constant support hangers and hydraulic snubbers are all shipped with travel stops (or shipping plug for a hydraulic snubber). These stops and plugs are necessary for shipment and ease of installation. The supports are pre-set at the specified ambient condition displacement. After installation of the pipe, these stops and plugs must be removed before operation. If travel stops are not removed, the support acts as a rigid support, and does not function as designed. After removal, the travel stops should be safely tied down and saved at the pipe supports for possible later use.   They are helpful if the pipe or supports are ever repaired, in the case of re-hydrotest, or other unusual situations.

FIGURE 6.1 VARIABLE SPRING ROD HANGER
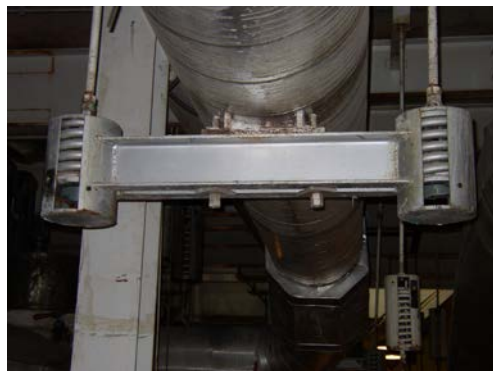
FIGURE 6.2 VARIABLE SPRING TRAPEZE ROD HANGER

FIGURE 6.3 VARIABLE SPRING FLOOR SUPPORT W/ STANCHION FROM PIPE TO SPRING LOAD FLANGE

FIGURE 6.4 CONSTANT SUPPORT ROD HANGER. SUSPENDED FROM STEEL

FIGURE 6.5   CONSTANT SUPORT ROD HANGER, RESTING ON STEEL

**FIGURE 6.6 CONSTANT SUPPORT HANGER, FLOOR TYPE BELOW PIPE;
PIPE HORIZONTAL MOVEMENT MUST BE LOW SINCE THIS IS UNSTABLE
ARRANGEMENT**

FIGURE 6.7 CONSTANT SUPPORT HANGER FLOOR SUPPORT WITH TOTALLY DIFFERENT INTERNAL MECHANISM THAN OTHERS SHOWN
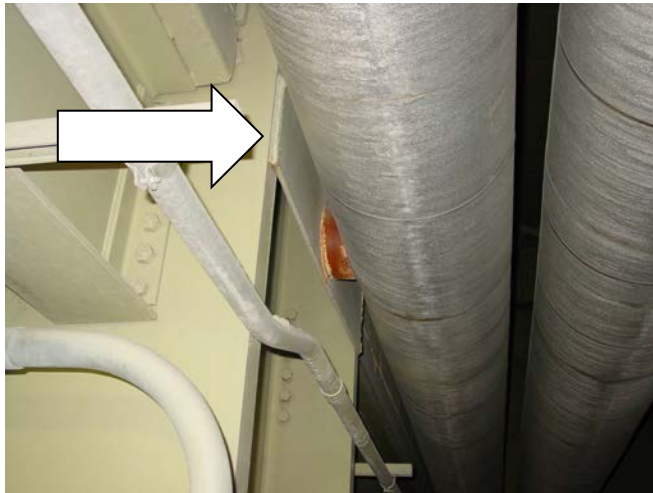
FIGURE 6.8 ANCHOR WELDED TO STEEL WITH STANCHION WELDED TO PIPE.

**FIGURE 6.9 LATERAL PIPE LIMIT STOP IN BOTH DIRECTIONS AND
AXIAL GUIDE**

**FIGURE 6.10 GUIDE ON RISER PIPE, ALSO NOTE VARIABLE SPRING ROD
HANGER ATTACHED TO STACHION BELOW GUIDE**

FIGURE 6.11 AXIAL RESTRAINT, (PIPE IS BEHIND STEEL) THESE TYPES OF SUPPORTS TEND TO BE ELABORATE DESIGNS AS SHOWN

FIGURE 6.12 SWAY BRACE

FIGURE 6.13 HYDRAULIC SNUBBER

7.0   PIPE STRESS ANALYSIS

Pipe stress analysis is a topic that requires its own training program. This section provides some limited considerations, and a checklist of the information that is needed for a complete analysis.

When starting the design of a plant, there may be a number of layout considerations, and in some cases the routing of the large diameter pipe may be a major limitation. In these cases, some preliminary analyses may be performed based on very conservative criteria to identify the best routing of the pipe. Conservative criterion is needed to assure that detailed design does not create changes that make the original routing unacceptable.

As the detailed design is developed, the analysis needs to be refined until it matches the actual design of the pipe. It is entirely appropriate to "optimize" the system by analysis, trying various routings and support configurations. The degree of optimization required is dependent on the complexity of the loading conditions and routing, the cost of the installed pipe, and the need to minimize operating and maintenance costs.

Less critical systems may be completely designed with design "rules of thumb" and the analysis is performed to confirm the detail design is acceptable.

As implied throughout this course, pipe stress results need to be evaluated based on allowable stresses, allowable equipment loads, reasonable pipe support loads, and pipe displacement for all loading conditions.

> *Pipe stress analysis results are only approximate models compared to actual installed systems. The great variety in components, materials, fabrication and supports leads to this inherent inaccuracy. For this reason, it is always recommended to be conservative in evaluating pipe stresses and movements. If a small increase in pipe stress would cause an excessive stress, or a small increase in loads would over load a nozzle, if at all possible, it is best to make modifications to increase the safety margin.*

See Table 7.1 for a list of information that a Piping Engineer needs for a final detailed analysis. Preliminary analyses can be made with assumed data, when appropriate.

TABLE 7.1 PIPE STRESS ANALYSIS DATA

ITEM	DESCRIPTION	COMMENT
1	Pipe Routing	Equipment to Equipment
2	Maximum Operating Temperature	
3	Maximum Operating Pressure	
4	Upset Pressure & Temperature	May be multiple upset conditions
5	Design Pressure & Temperature	
6	Design Code Rules	
7	Material Specifications	
8	Safety Relief Valve Set Pressures	
9	Movements at Equipment	
10	Allowable Loads at Equipment	
11	Pipe Support Locations	
12	Pipe Support Types	
13	Maximum Wind Speed	
14	Seismic Loading Condition	
15	Safety Valve Thrust Forces	
16	Weights of In-Line Components	
17	Local or National Applicable Laws	
18	Client Preferences	
19	Stiffness of Supports and Equipment	In some cases the stiffness is modeled to more accurately calculate loads
20	Vendor Supplied Pipe Design Information	For vendor supplied pipe to be included in analysis
21	Information Specific to Each Code for Design of Pipe Thickness	Joint Efficiency Factor, Location of Underground Pipelines
22	All Dynamic Loading Conditions	
23	Any Special Static Loading Conditions	Such as Batch Operation
24	Corrosion Allowance	
25	Stress Intensification Factors	Branches, Elbows, Special Fittings

8.0   SUMMARY

Piping Engineering in industrial plants requires solutions to a complex set of problems. A thorough understanding of the design conditions is required to start a detailed design. Client preferences, industry standards, standard material tolerances, expected operating procedures and expected maintenance procedures should be included in engineering considerations.

While the overall goal of Piping Engineering is

"To assure the installed pipe will perform reliably and safely in all expected conditions for its design life"

In the final analysis, the piping engineer and those working on the engineering team should always be thinking,

"WHAT IS REQUIRED FOR ME TO BE SAFE STANDING NEXT TO THIS PIPE WHILE IT IS OPERATING?"